Preprint
UCRL-JC-149436

Photon Colliders

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This article was submitted to International Conference on High Energy Physics, Amsterdam, The Netherlands, July 24-31, 2002

October 7, 2002

U.S. Department of Energy

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A photon collider interaction region has the possibility of expanding the physics reach of a future TeV scale electron-positron collider. A survey of ongoing efforts to design the required lasers and optics to create a photon collider is presented in this paper.

1. Photon-Photon Interactions

The idea for creating a photon-photon collider by adding high power lasers to an electron linear collider was proposed by Ginzburg *et al.* [1] in the early 1980s. Such a machine opens up new possiblities for the study of elementary particles. The Higgs boson can be produced in photon-photon collisions through a loop diagram in which all particles with charge and mass contribute. This diagram provides an opportunity to search for new particles of arbitrarily high mass through their effects on the loop. Additionally, control of the laser polarization allows some control over the spin and charge-parity state of the initial two photon system. This provides a unique mechanism to study the properties of a Higgs boson. Two photon collisions also provide a mechanism of charged particle production that has only electromagnetic contributions at the tree level. This would alleviate the theoretical uncertainties in particle production commonly encountered at other machines. The physics potential of such a machine is the subject of on-going study.

2. Photon Collider Hardware

The basic idea of a photon collider interaction region is shown in Figure 1. As the electron beams converge to the interaction point (IP) they are intercepted by laser pulses a few millimeters from the IP. A large fraction of the incoming electrons, ~60%, undergo a Compton backscatter and produce a high energy photon. The Compton backscattering process has been studied in detail [2] and simulation programs to model and parameterize the luminosity exist [3–6].

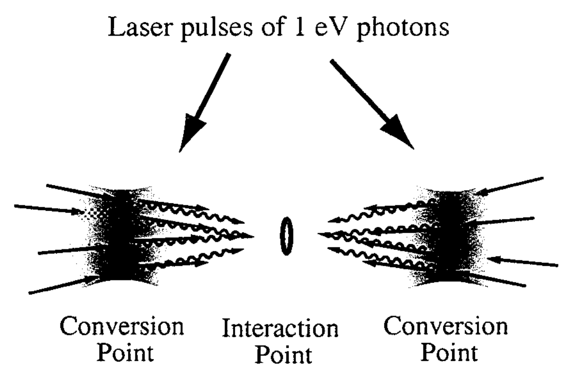

Figure 1. A schematic diagram of the photon collider interaction point. The high energy Compton backscattered photons focus to the same spot size as the electron beam.

In order to achieve a high luminosity of photon collisions, each electron bunch must be intercepted by a laser pulse. A laser pulse of 1 Joule compressed to 1 picosecond is required to achieve the ~60% Compton backscattering rate. This must then be multiplied by the repetion rate of proposed machines such as NLC [7] and TESLA [8] to compute the average laser power required. A single pass system that used each laser

*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

pulse once would require around 20kW of average power. A formidable number which pushes the state of the art in laser engineering.

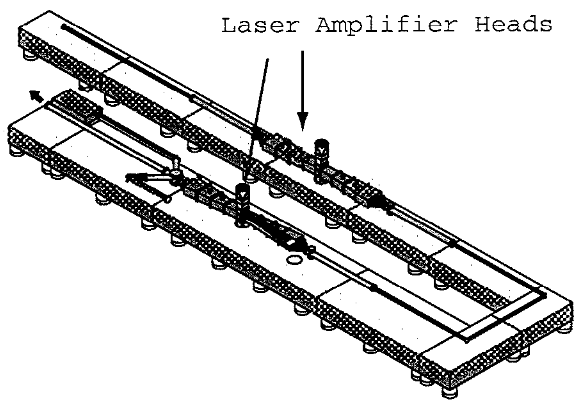

Figure 2. The layout of the MERCURY laser. Each laser head contains diode-pumped solid-state Yb:S-FAP crystals that are cooled by helium gas flow.

A design of the laser architecture for the NLC has been produced, based on the MERCURY [9] laser under construction at LLNL. The MERCURY laser, as shown in Figure 2, is designed to be a high average power solid-state laser producing 100 Joule pulses at one micron wavelength at a repetion rate of 10 Hz. An array of 12 of these lasers can be fired sequentially to match the 120 Hz repetition rate of the NLC. The single 100 Joule pulse can then be subdivided and time delayed using a series of optical splitters and delay lines to produce a train of 100 one Joule pulses separated by 2.8 ns. This would provide one laser pulse for every electron bunch in the machine. A system of focusing mirrors in the interaction region (IR) allow each laser pulse to be used twice, providing laser pulses for each arm of the linear accelerator. The layout of the focusing optics is shown in Figure 3.

While the technical solution proposed for NLC could be adapted to TESLA, the 5 Hz repetition rate of TESLA does not use the MERCURY laser efficiently. To use this architecture, TESLA would require 2-3 times more average power and the development of high average power electro-optical switches. An alternative architecture [10] which takes advantage of the large inter-bunch spacing of TESLA is under development at the Max Born Institute. A single laser pulse travels around a ring colliding with all of the bunches, as shown in Figure 4. This greatly reduces the required laser power, but requires high precision in the construction of the optical cavity.

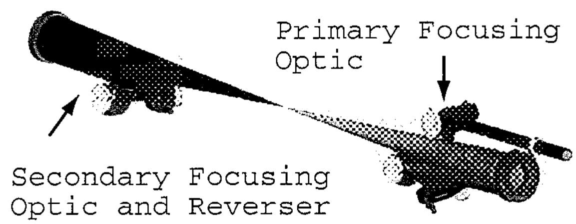

Figure 3. The arrangement of focusing optics which are contained within the accelerator's beam pipe. This is a two-pass system in which each laser pulse collides with two electron bunches, one from each arm of the accelerator.

3. Future Work

The MERCURY laser has begun commissioning at lower pulse energy and repetition rate. It is expected to be operating at full power by fall of 2003. A prototyping effort for the TESLA optical ring is proposed for the Max Born Institute.

While the conceptual designs for a photon collider are maturing, a photon collider of this type has never been demonstrated. The existence of the Stanford Linear Collider offers the opportunity [11] for a proof-of-principle demonstration of the integration of the photon collider optics into a real IR with the ability to produce and observe actual photon-photon luminosity. Such a demonstration would provide technical risk reduction for a photon collider experiment at a future TeV scale linear collider.

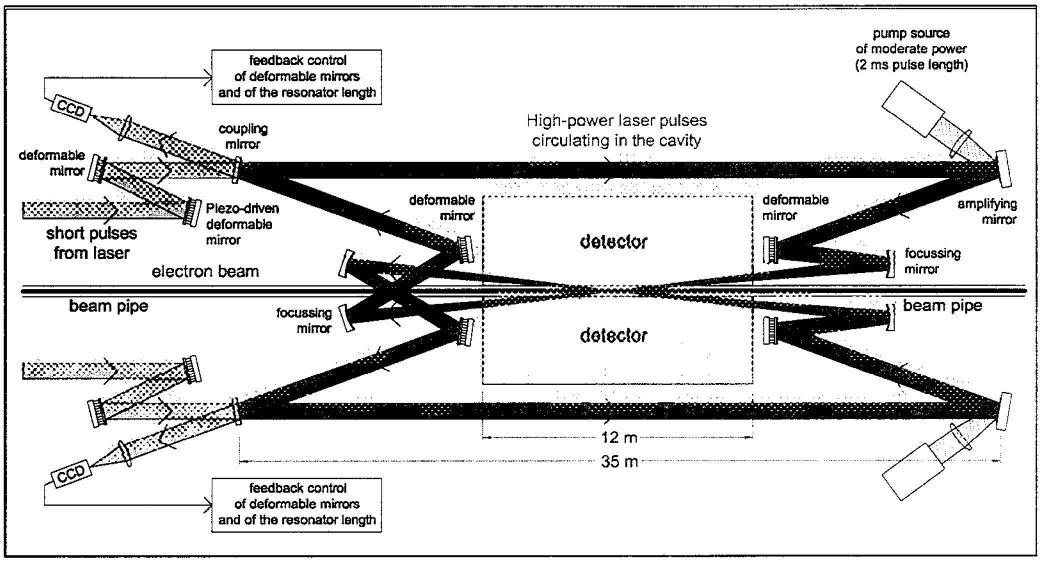

Figure 4. A diagram of the ring laser proposed for TESLA. The inter-bunch spacing of TESLA allows the laser pulse to travel around the outside of the detector before the arrival of the next electron bunch. Figure courtesy of K. Moenig, DESY.

4. Conclusion

No conceptual obstacles to the construction of a photon collider experiment have been discovered. The designs have reached the level of maturity where prototyping and systems demonstration are the next steps.

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